GALAXY EVOLUTION: INTERNALLY OR EXTERNALLY DRIVEN?

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RESUMEN

El resumen será traducido al español por los editores. The globally-averaged star formation rate in the Universe has been steadily declining since at least $z \sim 1$. This may be due either to very local processes operating within the average galaxy, or to external, environmental effects. Specifically, the build-up of structure may be responsible for terminating star formation in some galaxies and thus decreasing the global average. We summarize our previous and ongoing work to distinguish between these possibilities, by determining the average star formation rate as a function of redshift and environment, out to $z = 0.5$.

ABSTRACT

The globally-averaged star formation rate in the Universe has been steadily declining since at least $z \sim 1$. This may be due either to very local processes operating within the average galaxy, or to external, environmental effects. Specifically, the build-up of structure may be responsible for terminating star formation in some galaxies and thus decreasing the global average. We summarize our previous and ongoing work to distinguish between these possibilities, by determining the average star formation rate as a function of redshift and environment, out to $z = 0.5$.

Key Words: **GALAXIES: CLUSTERS**

1. INTRODUCTION

There is good observational evidence that the total amount of star formation in the universe has declined substantially over the past few Gigayears (Lilly et al. 1996; Wilson et al. 2002). This may be a reflection of local physics on galactic scales, whereby galaxies consume their gas supply as time progresses, and star formation gradually declines. However, observations show that star formation is inhibited in dense environments (Balogh et al. 1997; Balogh et al. 1998). In hierarchical models of galaxy formation, the abundance of dense clusters increases with time; therefore, perhaps the growth of structure is partly driving the decline in global star formation. However, this scenario is only viable if a suppression of star formation is observed in environments less extreme than rich clusters, since the latter are too rare to have a significant impact on the globally averaged star formation rate (SFR).

We can attempt to distinguish between these two interpretations by tracing the SFR as a function of environment at a series of redshifts. If the SFR–local density correlation is independent of redshift, there will be evidence that the global decline is due to environmental effects, coupled with the hierarchical growth of structure. To address this, we have begun a large programme to measure SFRs in different environments out to $z \sim 0.5$. The focus is on relatively low-density environments, since these have not been studied in much detail, and are common enough to contribute significantly to the global average.

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2. THE LOCAL UNIVERSE: SDSS AND 2DFGRS

Recently, data from the SDSS and 2dFGRS have allowed the precise measurement of the local SFR-environment correlation. Both Lewis et al. (2002) and Gomez et al. (2002) measure a large decrease in the number of strong Hα-emitting galaxies in dense regions. Furthermore, they show evidence that this trend may be independent of the morphology-density relation (Dressler 1980). Both studies identify a critical density of 1 galaxy ($M_b < -19$) per Mpc^2, below which no further increase in Hα strength is observed. This implies that environmental effects become important in regions more dense than large galaxy groups, which contain a substantial fraction of the mass in the Universe.

3. INTERMEDIATE REDSHIFTS

For the purpose of exploring lower mass systems at higher redshifts, we[2] have selected ten clusters at $z \sim 0.25$ with the lowest detectable X-ray fluxes, from the catalogue of Vikhlinin et al. (1998). For each cluster we have obtained *HST* WFPC images in the F702W filter of the central regions, combined

[2]In collaboration with B. Ziegler, R. Davies & I. Smail.

with ground-based spectroscopy from Calar Alto and WHT over a wider field. The morphological composition of the clusters is analysed in Balogh et al. (2002a), while we consider the spectroscopic properties in Balogh et al. (2002b). We find that the galaxy populations of these clusters are remarkably similar to those in more commonly studied clusters, which have masses an order of magnitude larger (see Figure 1). This suggests that processes like ram-pressure stripping, which are only expected to operate in the dense cores of massive clusters, are not responsible for the environmental dependence of morphology and SFR.

It is becoming increasingly clear that direct evidence for environmental effects on galaxies is likely to be found in dense groups, especially at higher redshift (Kodama et al. 2001). Therefore, we[3] have also begun an ambitious observational programme using LDSS2 on the Baade (Magellan I) telescope to study galaxy groups at $z \sim 0.45$, selected from the CNOC2 redshift survey (Carlberg et al. 2001). The original group catalogues are derived from a sparse-sampled spectroscopic survey; our programme is designed to complete the spectroscopy in the fields of these groups, and to probe one magnitude fainter. To date, a total of 728 spectra in the fields of ~ 30 groups have been obtained, in addition to the existing spectroscopy. From these spectra, we will obtain a complete census of each group, and measure the equivalent width of [O II]λ3727. Preliminary results show that emission lines are much more common amongst group members than in clusters at similar redshifts. The mean EW([O II]) of a preliminary sample of 12 groups is 10.2 Å, similar to that of the field at $z \sim 0.3$, but somewhat lower than expected at the mean group redshift of z=0.45 (see Figure 1).

4. SUMMARY OF RESULTS

Our goal is to construct the star formation history of the universe as a function of galaxy environment. Figure 1 shows how the mean EW([O II]) within the virial radius depends on environment and redshift, for our present sample of groups and clusters. Surprisingly, the amount of emission in clusters is approximately constant with redshift, so the difference between the cluster and field SFR *increases* with redshift. This suggests that, at least at cluster densities, the average SFR is determined by local environment, and not an internal galaxy clock. On the other hand, galaxy groups at $z \sim 0.4$ have SFRs

[3] In collaboration with J. Mulchaey, A. Oemler, R. Carlberg and S. Morris.

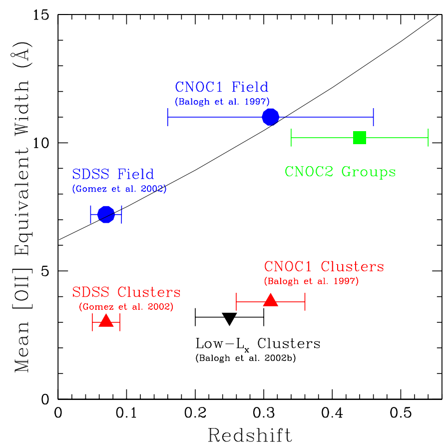

Fig. 1. The mean [O II] equivalent width in each of the samples discussed here. The results for the $z \sim 0.4$ groups are based on a preliminary sample of 12 groups. The other values are based on published results. Horizontal error bars show the redshift range of each sample. Vertical error bars are omitted, as the statistical errors on the mean are much smaller than the sample variance (which is large and would clutter the plot). The solid line shows a scaling of $(1+z)^2$, which is approximately the observed global rate of evolution (Wilson et al. 2002).

only slightly lower than the expected global average at that redshift. If SFR is entirely environment-dependent, this means that the local analogues of these groups should have substantially higher SFRs than the average.

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